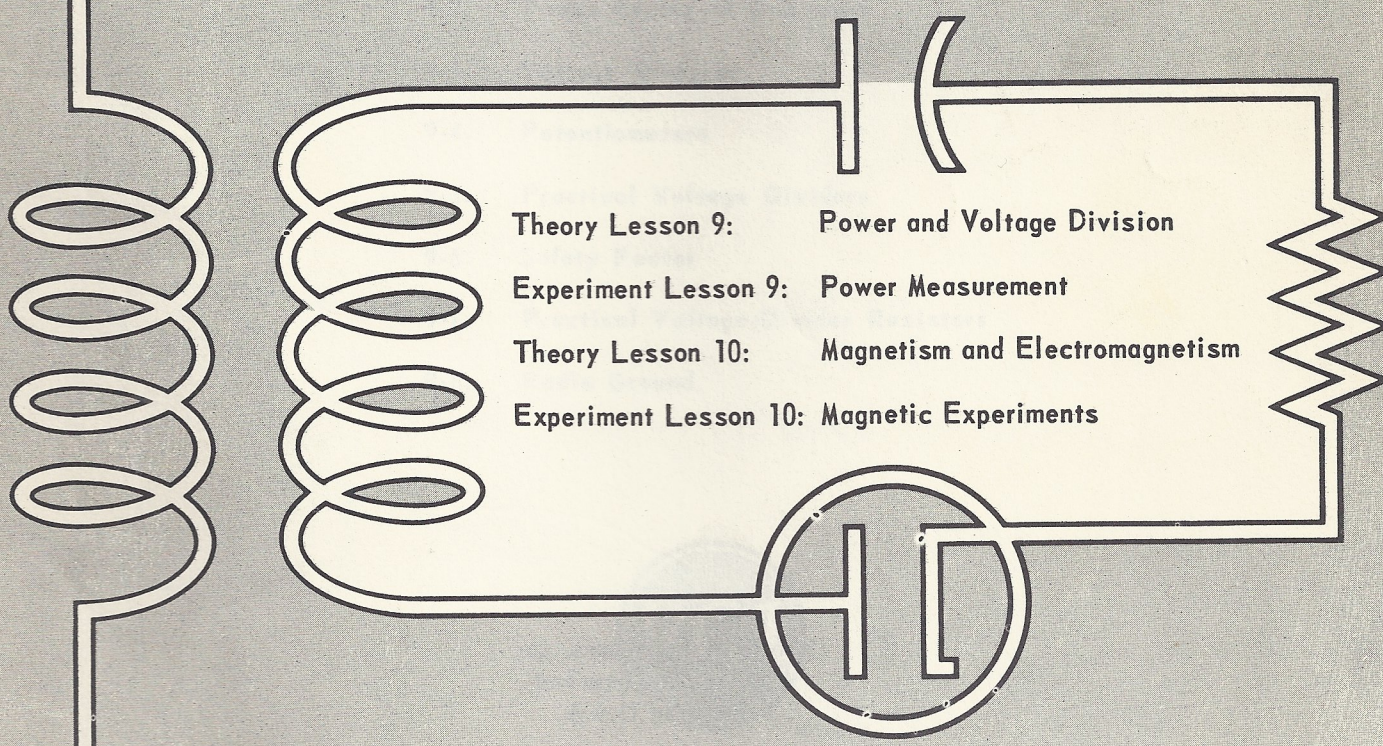


ELECTRONIC FUNDAMENTALS



Theory Lesson 9: Power and Voltage Division
Experiment Lesson 9: Power Measurement
Theory Lesson 10: Magnetism and Electromagnetism
Experiment Lesson 10: Magnetic Experiments

RCA INSTITUTES, INC.

A SERVICE OF RADIO CORPORATION OF AMERICA
New York, N. Y.



ELECTRONIC FUNDAMENTALS

THEORY LESSON 9

POWER AND VOLTAGE DIVISION

- 9-1. Electrical Power
- 9-2. Power Rating of Resistors
- 9-3. Voltage Division
- 9-4. Potentiometers
- 9-5. Practical Voltage Dividers
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Theory Lesson 9

INTRODUCTION

In earlier lessons, you learned that before electric current can flow in a circuit, the electrical pressure (voltage) must overcome the opposition to current flow caused by the resistance of the circuit. You know that there is no such thing as a perfect conductor, and that all electrical circuits offer some resistance to the flow of current. The electrical energy used in overcoming the resistance produces heat. Unless the purpose of the circuit is for heating, this energy that produced it is wasted.

9-1 ELECTRICAL POWER

A power line that carries electricity from a central generating plant to a house ten miles away, as shown in Fig. 9-1, uses up

electric power. To see how this is so, let's put it in figures. Let the resistance of the power line be 5 ohms and the current flowing through it be 4 amperes. Then:

$$E = I \times R = 4 \times 5 = 20 \text{ volts}$$

If the voltage at the generator is 120 volts, then the voltage available at the house (with 4 amperes flowing) is only 100 volts. Twenty volts is lost in the power line.

In Lesson Five, you learned that power is the rate of using energy, and that the unit of electrical power is the *watt*. In d-c circuits, Ohm's Law for power is: Power (in watts) is equal to the product of the voltage and the current. This is written:

$$P = E \times I, \text{ or } P = EI$$

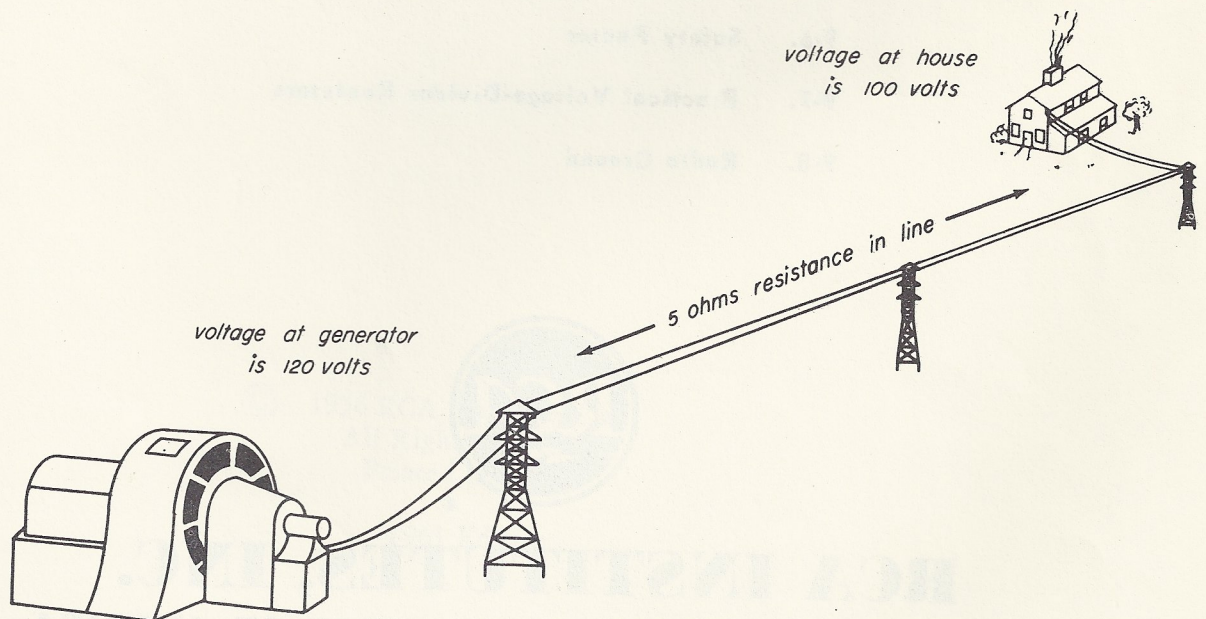


Fig. 9-1

So, if the voltage in the power line is 20 volts and the current flowing through it is 4 amperes, then:

$$P = E \times I = 20 \times 4 = 80 \text{ watts}$$

This 80 watts is the power used up in the line. At the same time, the power used at the house may be written as:

$$P = E \times I = 100 \times 4 = 400 \text{ watts}$$

The power used at the house is useful power, while the power consumed in the line is wasted power.

There are other formulas that you can use in order to help you in finding power. For example, suppose that you do not know how much current is flowing but that you do know the resistance and the voltage. In such a case, you can find the power by using the following formula:

$$P = \frac{E^2}{R}$$

Here's how we get this formula. From Ohm's Law, we know that:

$$I = \frac{E}{R}$$

So, we substitute

$$\left(\frac{E}{R}\right) \text{ for } (I)$$

in the formula, $P = E \times I$, in this way:

$$P = E \times \frac{E}{R} = \frac{E^2}{R}$$

Let's see how this formula works in the example we used before. We know that the voltage drop in the power line is 20 volts and the resistance is 5 ohms. So:

$$P = \frac{E^2}{R} = \frac{20 \times 20}{5} = \frac{400}{5} = 80 \text{ watts}$$

Another formula for calculating power is:

$$P = I^2 R \quad \frac{P}{R} = I^2$$

Let's see how we get this formula. We know that $E = I \times R$, so if we substitute $(I \times R)$ for (E) in the formula, $P = E \times I$, we get $P = I \times R \times I = I^2 \times R$. Applying this formula to the same example as before, we know the current in the power line is 4 amperes and the resistance is 5 ohms. So:

$$P = I^2 \times R = 4 \times 4 \times 5 = 80 \text{ watts}$$

9-2. POWER RATING OF RESISTORS

Resistors must be able to *dissipate* (get rid of) the heat developed in them by the power they consume. The power (and heat) in the resistor increases rapidly as the current through it is increased, because the power depends upon the square of the current. Let's examine the change in power that takes place when there is a change in the amount of current. Let's assume that 5 amperes of current flows through a 100-ohm resistor. Then:

$$P = I^2 R = 5 \times 5 \times 100 = 2,500 \text{ watts}$$

If we double the value of the resistor, we get:

$$P = I^2 R = 5 \times 5 \times 200 = 5,000 \text{ watts}$$

However, if the current is doubled, then

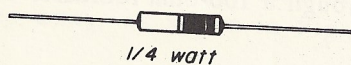
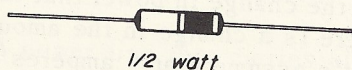
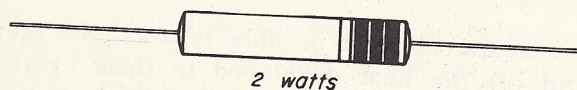
$$\begin{aligned} P &= I^2 R = 10 \times 10 \times 100 \\ &= 10,000 \text{ watts} \end{aligned}$$

This shows four times the power by doubling the current and only two times by doubling the resistance value. So, a little change in current can make a large change in power.

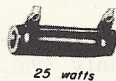
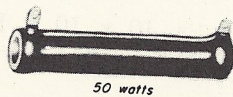
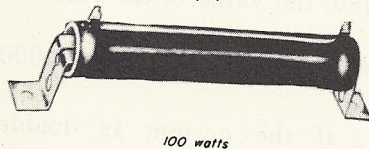
When a resistor is used within the rated limits, heat is able to escape from the resistor as rapidly as it is produced. When the resistor is overloaded (in other words, when it is caused to carry more power than it was made to), heat develops faster than it can escape. As you know, some resistive mater-

ials increase in resistance as the temperature rises and some carbon resistors decrease in resistance with a rise in temperature. In either case, the resistance in the overloaded circuit is no longer the same. This may make a great difference in the performance of the circuit. Of course, if the temperature rises high enough, the resistor may burn up.

The resistors used in radio and television are rated by the amount of power they can safely handle. Figure 9-2 shows some of the sizes of carbon composition and wirewound resistors used in radio and television receivers. As you can see, in general, the larger the resistor, the higher is its power rating in watts. Resistors made by most



about actual size
(a)



about 1/4 of actual size
(b)

Fig. 9-2

manufacturers can withstand some overloading without damage or excessive heat. However, it is good practice not to exceed the power indicated by the manufacturer's rating. Therefore, before choosing a resistor for an electric or electronic circuit, always be sure that it can handle the power required by the current flowing in the circuit. For example, if a circuit calls for a 4,000-ohm resistor with 10 ma flowing through it, we calculate the power:

$$P = I^2 R = 0.01 \times 0.01 \times 4,000 \\ = 0.4 \text{ watt}$$

However, if the current flowing through the resistor is increased to 20 ma, we find the power consumed is:

$$P = I^2 R = 0.02 \times 0.02 \times 4,000 \\ = 1.6 \text{ watts}$$

In the first case, we might use a 1/2-watt resistor. In the second case, a resistor with a 2-watt rating or higher is called for. We will have more to say about this later in this lesson.

9-3 VOLTAGE DIVISION

Resistors are often used in radio and television receivers to divide large voltages so that each individual circuit may receive the exact voltage it needs. How this is done can be explained simply. Figure 9-3 shows a 6-volt battery with two series resistors connected across its terminals. One resistor

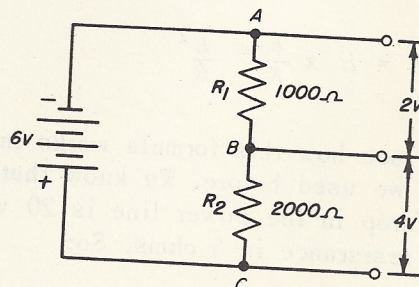


Fig. 9-3

has a resistance of 1,000 ohms; the other has 2,000 ohms. The voltage drop across R_1 and R_2 will be in proportion to the resistances of R_1 and R_2 . This means that R_2 , having twice the resistance of R_1 , will have twice the voltage drop across it. R_1 has one-third the resistance of the total resistance (R_1 and R_2 .) So, it has one-third of the total voltage across it. The resistor R_2 has two-thirds of the total resistance, so it has two-thirds of the voltage. So, between terminals B and C , a meter would measure four volts. Between terminals A and B , a meter would measure two volts. If we make R_1 one million ohms and R_2 two million ohms, the voltage drops are still the same because the ratio of the resistances is the same. If R_1 were 200 ohms and R_2 were 400 ohms, the voltage drops would be the same, for the same reason as before.

Let's use Ohm's Law to prove these statements. For example, in the original circuit, $R_t = 3,000$ ohms. Therefore:

$$I_t = \frac{E}{R} = \frac{6}{3,000} = 0.002 \text{ amp}$$

This is a series circuit, so:

$$\begin{aligned} I_t &= I_{R1} = I_{R2} \\ E_{R1} &= I_{R1} \times R_1 = 0.002 \times 1000 \\ &= 2 \text{ volts} \\ E_{R2} &= I_{R2} \times R_2 = 0.002 \times 2000 \\ &= 4 \text{ volts} \end{aligned}$$

In the second resistor combination, R_1 equals 1 megohm, and R_2 equals 2 megohms. Therefore:

$$\begin{aligned} R_t &= R_1 + R_2 = 3 \text{ megohms} \\ I_t &= \frac{E}{R_t} = \frac{6}{3,000,000} = 0.000002 \text{ amp} \\ I_t &= I_{R1} = I_{R2} \\ E_{R1} &= I_{R1} \times R_1 = 0.000002 \\ &\times 1,000,000 = 2 \text{ volts} \\ E_{R2} &= I_{R2} \times R_2 = 0.000002 \\ &\times 2,000,000 = 4 \text{ volts} \end{aligned}$$

In the third case, R_1 equals 200 ohms and R_2 equals 400 ohms. So:

$$R_t = R_1 + R_2 = 200 + 400 = 600 \text{ ohms}$$

$$I_t = \frac{E}{R_t} = \frac{6}{600} = 0.01 \text{ amp}$$

$$I_t = I_{R1} = I_{R2}$$

$$E_{R1} = I_{R1} \times R_1 = 0.01 \times 200 = 2 \text{ volts}$$

$$E_{R2} = I_{R2} \times R_2 = 0.01 \times 400 = 4 \text{ volts}$$

From this we can see that, in a series circuit, the voltage drops are in proportion to the resistance of each part of the circuit. We may use this same principle to divide any voltage in any needed amounts. Bear in mind, however, that this method of voltage division may be used only when voltage is needed *without current flow*. This means that if a circuit is connected to points B and C , as in Fig. 9-4, no current may be drawn by the applied circuit. Where voltage and current are both required, voltage dividers are calculated in an entirely different manner, as we will see later in this lesson.

When selecting resistors for this type of voltage divider, you must remember that the total resistance acts as a load to the voltage source. While voltage-divider circuits offer an equal load to any equal voltage source, the power lost in voltage-divider resistors is sometimes more important when the voltage source is a battery. This is because of the relatively high cost of battery power, especially primary-battery power. If the voltage source is a battery, therefore, it is desirable to select resistors of high values so that little load is placed on the battery.

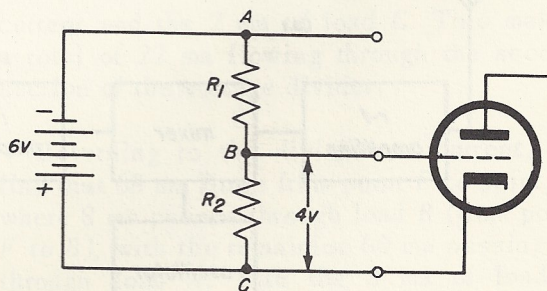


Fig. 9-4

9-4 POTENTIOMETERS

In radio and television, a potentiometer is a resistor with a movable sliding arm. It usually looks like the one shown in Fig. 9-5a. Inside, it may look something like the one shown in Fig. 9-5b. The resistor may be either wirewound or carbon. One end of the resistor is connected to terminal *A* and the other end is connected to terminal *B*. The sliding arm is connected to the center terminal *C*. The moving arm may be adjusted so that it touches any part of the resistor. Figure 9-5c shows a schematic diagram of a potentiometer with its terminals *A* and *B* connected to a voltage source. Moving the arm toward terminal *A* causes the greater portion of the source voltage to appear across terminals *C* and *B*. Moving the arm closer to terminal *B* causes less of the source voltage to appear between *C* and *B*. As we know from the earlier part of the lesson, the percentage of the source voltage across *C* and *B* will be the proportion of the resistance of *C* and *B* to the total resistance. Practically all volume controls of all radios make use of the potentiometer. Fig. 9-5d shows a combination block and schematic diagram showing a volume-control circuit widely used in radio and television receivers.

9-5 PRACTICAL VOLTAGE DIVIDERS

Up until now, we have considered voltage dividers that provide different voltages without drawing current. In radio and television receivers, there is a need for such voltage dividers. However, there is also a great need in these receivers for voltage dividers capable of providing current at different voltages. A simple 5-tube radio receiver may draw current from its power-supply section at three or four voltage levels. For example, let's consider a receiver that requires 60 ma at 250 volts, 8 ma at 100 volts, and 2 ma at 75 volts. To figure the value of resistance needed for such a voltage divider requires a knowledge of Ohm's Law.

Sometimes the voltage divider circuit of a receiver uses a single wirewound resistor with taps similar to those shown in Fig. 9-6a. Figure 9-6b shows such a resistor connected to the power-supply section of a radio receiver. We do not know, at this time, the values of R_1 , R_2 , and R_3 . We must find them. Because we are not ready to discuss the parts that make up a power supply, the power-supply section is shown as just a box with two terminals. The total voltage

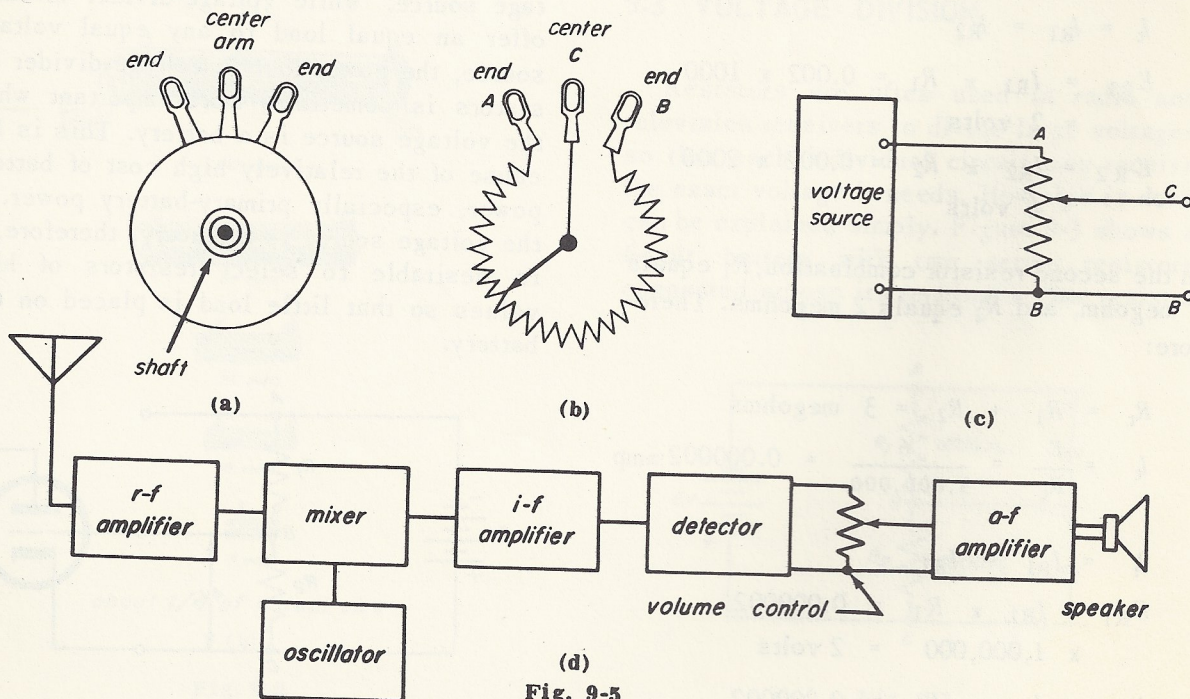


Fig. 9-5

delivered by the power supply is 250 volts, selected because it supplies the maximum voltage required in the problem presented in the paragraph above. This voltage appears across the ends of the voltage divider resistor at terminals *A* and *D*.

The receiver in our problem requires a total of 70 ma of current. When designing power supplies and figuring the values of voltage-divider resistors, it is customary to include a certain amount of current that is called *bleeder current*, which flows through the voltage-divider resistor at all times when the power supply is turned on. The reason that bleeder current is included is discussed fully in a later lesson on power supplies. For our problem, we will assume a value of 20-ma bleeder current. Therefore, the total current drawn from the power supply is 90 ma, which we find by adding the currents as follows:

$$\begin{array}{r}
 60 \text{ ma at 250 volts} \\
 8 \text{ ma at 100 volts} \\
 2 \text{ ma at 75 volts} \\
 \hline
 20 \text{ ma bleeder current} \\
 \hline
 90 \text{ ma total current}
 \end{array}$$

The currents drawn from the power supply and voltage divider circuit are used in certain electronic circuits that include electron tubes and other radio parts. The 60 ma at 250 volts may supply correct operating potentials to the electrodes of several tubes. However, this 60-ma load on the power supply may be represented by a resistor, as in Fig. 9-6c. This load is shown in the diagram as a resistor labeled load *A*. At the 100-volt level, 8 ma are required, and this is represented by load *B*. At the 75-volt level, 2 ma are required, and this is represented in the diagram by load *C*. By examining the diagram, it can be seen that the 60 ma current of load *A* does not flow through the voltage divider at all. Looking at Fig. 9-6c and d, if we follow the path of the current from the negative terminal of the power supply, we find that the current leaving the power supply is 90 ma. At point *D*, the current divides between *E* and *C* with 20 ma bleeder current flowing through the first section of the voltage divider resistor *R*₁.

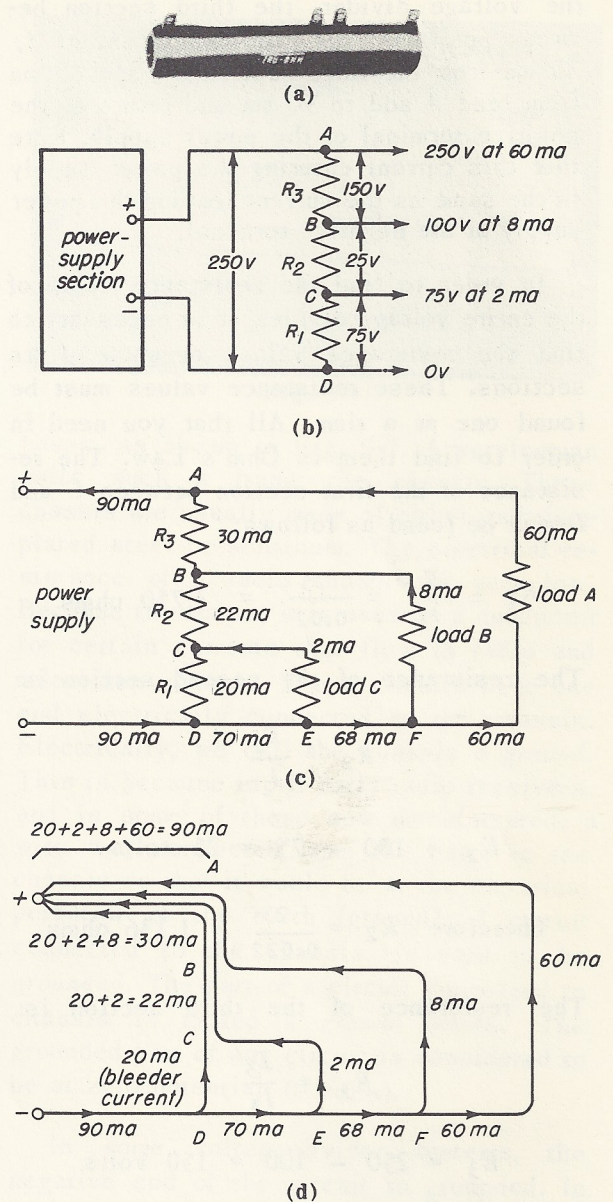


Fig. 9-6

The remaining 70 ma flow on from *D* to *E*, where 2 ma flow through load *C* (between points *E* and *C*). The current flowing from *C* to *B*, in the second section of the voltage divider *R*₂ is the sum of the 20-ma bleeder current and the 2 ma of load *C*. This makes a total of 22 ma flowing through the second section of the voltage divider.

Returning to the division of current, we find that 68 ma flows from point *E* to point *F*, where 8 ma passes through load *B* (from point *F* to *B*), with the remaining 60 ma passing on through load *A*. With the 8 ma of load *B* added to the 22 ma of the second section of

the voltage divider, the third section between points *B* and *A* carries 30 ma. At *A*, 30 ma from the third section R_3 and 60 ma from load *A* add to 90 ma and return to the positive terminal of the power supply. Note that this current entering the power supply is the same as the current leaving the power supply at the negative terminal.

In order to find the resistance value of the entire voltage divider, it is necessary to find the resistance values of each of its sections. These resistance values must be found one at a time. All that you need in order to find them is Ohm's Law. The resistance of the first section between *C* and *D* may be found as follows:

$$R_1 = \frac{E}{I_1} = \frac{75}{0.02} = 3,750 \text{ ohms}$$

The resistance of the second section is:

$$R_2 = \frac{E_2}{I_2}$$

$$E_2 = 100 - 75 = 25 \text{ volts}$$

$$\text{Therefore } R_2 = \frac{25}{0.022} = 1,136 \text{ ohms}$$

The resistance of the third section is:

$$R_3 = \frac{E_3}{I_3}$$

$$E_3 = 250 - 100 = 150 \text{ volts}$$

$$\text{Therefore, } R_3 = \frac{150}{0.03} = 5,000 \text{ ohms}$$

To find the total resistance of the voltage divider, we add the individual resistance values. So:

$$R_t = R_1 + R_2 + R_3 = 3,750 + 1,136 + 5,000 = 9,886 \text{ ohms}$$

In addition to knowing how much resistance is in each section of a voltage divider, it is also necessary to figure the power rating. In calculating the power rating of a tapped wirewound voltage divider, we use the power formula, $P = I^2R$. The current used in the calculations must be the highest

current flowing in any part of the voltage divider. The highest current flowing through any section of the voltage divider is 30 ma. So:

$$P = I^2R = 0.03 \times 0.03 \times 9,886 = 8.9 \text{ watts (approximately)}$$

9-6 SAFETY FACTOR

Most radio, television, and other electronic engineers include a *safety factor* when calculating the power rating of resistors and other parts. The idea behind the safety factor is to allow for an overload. The safety factor generally used in calculating power ratings of resistors is two. This means simply that the actual power the resistor is supposed to handle is multiplied by two. So, applying the safety factor, we multiply 8.9×2 and get 17.8 watts. Tapped wirewound resistors for voltage dividers usually must be made to order. So, when ordering a quantity of these voltage-divider resistors, we would specify the nearest higher commercial size. In this case, 20-watt resistors would be used.

9-7. PRACTICAL VOLTAGE-DIVIDER RESISTORS

Tapped wirewound voltage-divider resistors are used in radios and television receivers. However, they are made to order for the particular receiver or circuit for which they are designed. This calls for special operations in manufacture. They are somewhat costly to replace when one section burns out or otherwise becomes defective. Some servicemen suggest replacing only the defective section with a single resistor of the proper value. Sometimes there is not enough space for another resistor. In such cases, the entire voltage divider must be replaced. However, even if there is enough space, the defective section may still cause trouble. So, the best practice is to replace the whole voltage divider, if at all possible. Resistors having adjustable taps can be used.

Today, in many pieces of equipment, the sections of a voltage divider are made

up of individual resistors. In most cases, these resistors are carbon composition resistors, which are considerably less expensive than wirewound resistors. Also, they take up, somewhat less space. What is more, if one resistor breaks down, it alone is the one to be replaced. Each is selected with a power rating based on the current flowing through it, which need not be as much as the maximum current flowing in the voltage divider circuit.

Let's see how using individual resistors cuts down on the power rating. The power of each resistor in Fig. 9-6 may be calculated separately:

$$P_{R1} = (I_{R1})^2 \times R_1 = 0.02 \times 0.02 \times 3,750 \\ = 1.5 \text{ watts}$$

$$P_{R2} = (I_{R2})^2 \times R_2 = 0.022 \times 0.022 \\ \times 1,136 = 0.54 \text{ watts}$$

$$P_{R3} = (I_{R3})^2 \times R_3 = 0.03 \times 0.03 \times 5,000 \\ = 4.5 \text{ watts}$$

By applying our safety factor, we find that R_1 should be a 3-watt resistor, R_2 should be 1.08-watt resistor, and R_3 a 9-watt resistor. Carbon composition resistors are normally produced with ratings of 1/2 watt, 1 watt, 2 watts, and sometimes 3 and 5 watts. Wirewound resistors are normally produced with ratings of 5, 10, 20, 25, 50, 80, and 100 watts. So, for our first resistor we would choose a standard 3-watt carbon composition resistor. Instead of ordering a 3,750-ohm resistor, we would order the nearest stock size, which might be either 3,600 or 3,900 ohms. For resistor R_2 , we would use a standard 1-watt resistor with a standard stock value of 1,100 ohms. For R_3 , we would select a standard 5,000-ohm, 10-watt wirewound resistor. These resistors would occupy much less space than one tapped wirewound resistor. What is more, if one resistor broke down, it alone would have to be replaced.

9-8. RADIO GROUND

Radio and television receivers are normally assembled on metal frames or

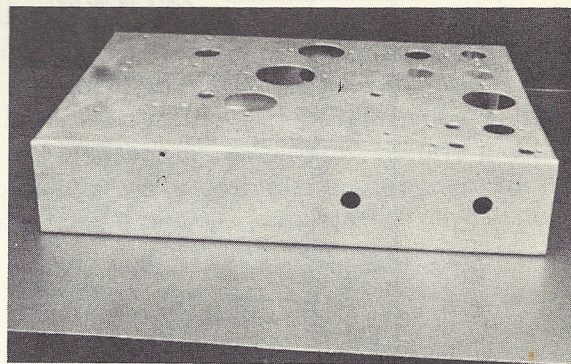


Fig. 9-7

bases, as shown in Fig. 9-7. A serviceman calls such a frame the *chassis*. These chassis are usually made of either cadmium-plated steel or aluminum. The electrical resistance of a radio chassis is very low. Because this is so, it is used as a conductor for certain currents that flow in radio and television circuits. These circuits have one end electrically connected to the chassis. Electrically, we call the chassis a *ground*. This is because in all early radio receivers, and in some of those now manufactured, a wire was connected from the earth to the chassis so that it would be at the electrical potential of the earth (ground). A circuit connected to the chassis, is said to be *grounded*. The part of a circuit connected to chassis is called a *ground return*. The grounded part of any circuit is considered to be at zero potential (0 volts).

In some voltage-divider systems, the negative end of the circuit is grounded. In some cases, however, it is necessary for one or more of the voltages needed in a receiver to be negative with respect to zero. When these voltages are obtained from the voltage-divider circuit, the negative end of the power supply is not connected to the chassis. Instead, some other point in the voltage divider is connected to the chassis (ground), as shown in Fig. 9-8. In this voltage divider, point *D* is grounded (as shown by the ground symbol). All voltages in a positive direction from point *D* are said to be *above ground*, and all voltages in a negative direction from point *D* are said to be *below ground*. All voltages above ground are measured with ground as the negative end and all voltages below ground are measured with ground as the positive end. Ground is, there-

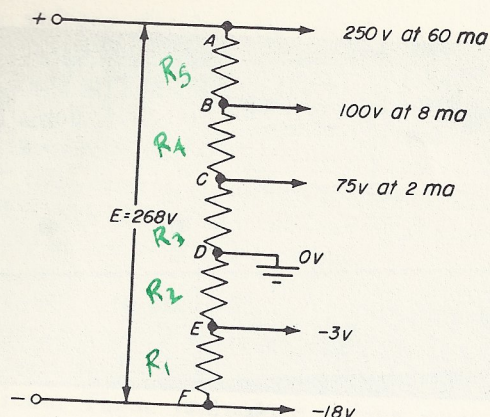


Fig. 9-8

fore, a reference point with a potential of zero volts. We could ground any point of the voltage-divider circuit. All we need do is to change a few circuit connections in the radio or television receiver. For example, we could ground the positive end of the voltage supply and have all of the voltages negative with respect to ground. However, radio and television receivers are designed so that some voltages are above ground and some are below ground.

The voltage divider shown in Fig. 9-8 has two voltage levels that are negative with respect to ground. One is -3 volts and the other is -18 volts. The total voltage delivered by the power supply is 268 volts, which is the sum of the 250 volts above and the 18 volts below ground.

This voltage divider differs in several ways from the one we just calculated. For us to understand these differences, it is nec-

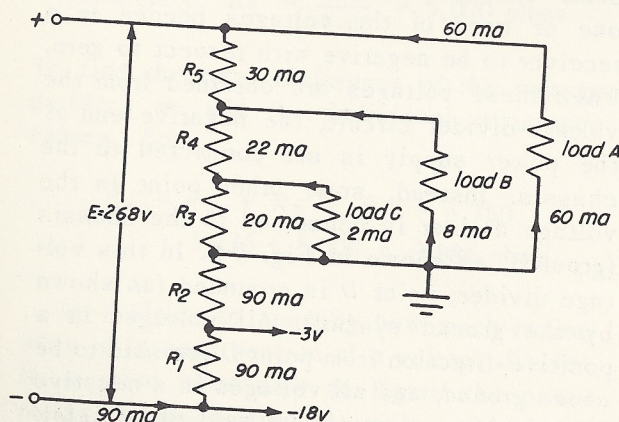


Fig. 9-9

essary to calculate the resistance values of each section of such a voltage divider. In order to simplify our problem, we will use the same current requirements as in the last voltage divider. Therefore, we will assume that we need 60 ma at 250 volts, 8 ma at 100 volts, 2 ma at 75 volts, with 20 ma of bleeder current. The negative voltages are used for their potentials only, and no current is needed at these points. Figure 9-9 shows the voltage divider with resistors representing the three current loads. Because no current is drawn at the -3-volt and -18-volt levels, no load is shown at these points. The diagram also shows the current paths. Examine the diagram carefully and you will see that the negative return of the three load circuits is at the zero potential, or ground level. Therefore, the entire 90 ma delivered by the power supply passes through the first and second sections of the voltage divider (R_1 and R_2). With this knowledge we can calculate the resistance values of each section of the voltage divider:

$$R_1 = \frac{E_{R1}}{I_{R1}}$$

E_{R1} is the difference between -3 and -18 volts, which is 15 volts. Therefore:

$$R_1 = \frac{15}{0.09} = 167 \text{ ohms}$$

In a similar manner,

$$R_2 = \frac{E_{R2}}{I_{R2}} = \frac{3}{0.09} = 33 \text{ ohms}$$

$$R_3 = \frac{E_{R3}}{I_{R3}} = \frac{75}{0.02} = 3,750 \text{ ohms}$$

$$R_4 = \frac{E_{R4}}{I_{R4}} = \frac{25}{0.022} = 1,136 \text{ ohms}$$

$$R_5 = \frac{E_{R5}}{I_{R5}} = \frac{150}{0.03} = 5,000 \text{ ohms}$$

As you can see, this voltage divider differs from the first one in the two added resistance sections and in the amount of applied voltage. However, if we use a single tapped wire-wound resistor for this voltage divider, we will see a considerable difference in the power rating of this voltage divider as compared with the first one. As you know, the power rating of a single voltage-divider resistor is determined by the greatest current flowing in any section. The highest current flowing in this voltage divider is the 90 ma flowing through R_1 and R_2 . Adding the resistance values of the five sections of the voltage divider, we get a total of 10,086 ohms. The power rating of the voltage-divider resistor is:

$$\begin{aligned} P &= I^2 R = 0.09 \times 0.09 \times 10,086 \\ &= 82 \text{ watts} \end{aligned}$$

Multiplying 82 watts by our safety factor, 2, we see that a resistor with 160-watts rating is needed, which is considerably more than the 20-watt rating of the first voltage divider. In this case, therefore, it definitely pays to break the voltage divider up into separate resistors. Then:

$$\begin{aligned} P_{R2} &= (I_{R2})^2 \times R_2 = 0.0081 \times 33 \\ &= 0.27 \text{ watts} \end{aligned}$$

In this case a 1/2-watt carbon resistor will do very nicely.

$$\begin{aligned} P_{R1} &= (I_{R1})^2 \times R_1 = 0.0081 \times 167 \\ &= 1.4 \text{ watts} \end{aligned}$$

Here, a standard 3-watt carbon resistor, or a 5-watt wirewound resistor will handle the power. The remaining three resistors are rated the same as in the previous problem.

